Fermi National Accelerator Laboratory

Top Quark Results at CDF

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We present the latest results on the top quark obtained by the CDF experiment using a data sample of about 110 pb^{-1} collected at the Fermilab Tevatron collider. We briefly describe the candidate events selection and then discuss the production cross section determination and the mass measurement. The study of two new decay channels (all hadronic and "tau dilepton") is also reported.

1. INTRODUCTION

At the Tevatron energy ($\sqrt{s} = 1.8\ TeV$) top quarks are produced primarily via the process $q\bar{q} \to t\bar{t}$. In the Standard Mode each top quark decays almost exclusively into a real W and a b quark ($t \to Wb$). Each W subsequently decays into either a charged lepton and a neutrino or two quarks. The $t\bar{t} \to W^+bW^-\bar{b}$ events can thus be identified by means of different combinations of energetic leptons and jets.

CDF searched for the top quark using most of these signatures. The branching ratio for both W's from a $t\bar{t}$ pair to decay leptonically is: 2/81 for $e\mu$, $e\tau$, $\mu\tau$ and 1/81 for ee, $\mu\mu$, $\tau\tau$ (dilepton channels). Decay modes of $t\bar{t}$ pairs in which one W boson decays hadronically and the other leptonically (single lepton channel) have a branching ratio of 24/81. When both W's decay hadronically (all hadronic channel) the branching ratio is 36/81. Recently a top signal has been identified in this channel as well.

The CDF data was collected during two running periods (run 1A and run 1B) from 1992 to the end of 1995. Both a counting experiment [1] and a kinematic study ("event structure") [2] were performed with the data from run 1A (19.3 pb^{-1}). The first direct evidence of the presence of top events in the data reported in these analyses was confirmed by an improved version of the counting experiment, using a larger data sample (67 pb^{-1}) [3]. The event structure analysis was also updated using more statistics and confirmed the previous result [4]. Other kinematic studies were performed and published [5]. The D0 Collabora-

tion also observed the production and decay of top quark pairs [6].

One year after the top discovery, the analysis has naturally shifted from a search–oriented strategy to measuring the top quark properties with the best possible accuracy.

Here we report the results obtained on the full 1A + 1B data sample ($\approx$ 110 pb^{-1}). We briefly describe the various samples selection and the results obtained in all the channels. We then focus on the production cross section determination and the top mass measurement.

2. DILEPTON CHANNEL

In the standard dilepton channels (ee, $\mu\mu$ and $e\mu$) the event topology consists of two oppositely charged high P_T leptons, large missing energy $\not{E}_T$ to account for the presence of two undetected neutrinos and two jets to account for the b quarks. The selection starts requiring the two leptons to be of opposite sign and to have $P_T \geq 20\ GeV/c$ and at least one lepton to have $|\eta| \leq 1.0$ and to be isolated. We then require $\not{E}_T \geq 25\ GeV$ and two jets with $E_T \geq 10\ GeV$ and $|\eta| \leq 2.4$. We remove ee and $\mu\mu$ pairs with $75\leq M_{ll} \leq 105$ GeV/c^2, to suppress the background from Z production. Additional background rejection is obtained by requiring that the $\not{E}_T$ vector should not be within 20 degrees of any jet or lepton in the transverse plane, for events with $\not{E}_T \leq 50\ GeV$. Ten events survive these cuts: 7 $e\mu$, 2 $\mu\mu$ and 1 ee candidates (Fig. 1).

The total background amounts to 2.0 $\pm$ 0.4 events. It can come from WW production, direct

$b\bar{b}$ production, $Z \to \tau\tau$, Drell–Yan and hadrons misidentified as leptons.

Looking for the presence of b jets in the dilepton candidates, we find 4 events containing at least one jet identified as a b jet.
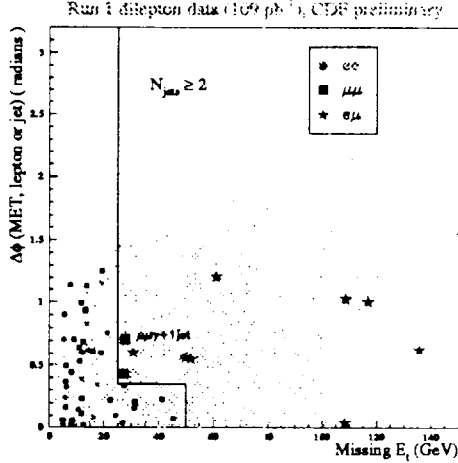

Figure 1. Azimuthal angle between $\not{E}_T$ and the nearest lepton or jet, versus the $\not{E}_T$ for standard dilepton events. The line represents the $\not{E}_T$ cut. The small dots show the expected distribution for $t\bar{t}$ events ($M_{top} = 175 \ GeV/c^2$).

Recently the dilepton search has been extended to the channel where one of the leptons is a τ. This allows to increase the acceptance for top quark decay. We look for τ's in their hadronic mode, which represents 64% of the total. Each τ decay involves an undetectable neutrino, which decreases the kinematic acceptance for the τ decay products. The total acceptance for τe, $\tau\mu$ is therefore smaller than for standard dileptons.

The primary lepton is selected as in the standard dilepton analysis. The presence of two jets is required as well. Additional background rejection is obtained cutting on the $\not{E}_T$ significance ($\sigma_{\not{E}_T} = \not{E}_T/\sqrt{\Sigma E_T} \geq 3 \ GeV^{1/2}$) and on the total transverse energy H_T of the event ($H_T \geq 180 \ GeV$). Due to the softer P_T spectrum for τ decay products, we require $P_T(\tau) \geq 15 \ GeV$. We impose the τ candidate tracks to be isolated and reject tracks associated to a calorimeter energy

deposition consistent with coming from an e or μ. The selection yelds 4 candidate events, 2 $e\tau$ and 2 $\mu\tau$, corresponding to the four points above the cut on $\not{E}_T$ significance in Fig. 2. Three of them show evidence of b quarks in their jets. The total background is computed to be 1.96 ± 0.35 events. The main contribution comes from jets misidentified as τ's.
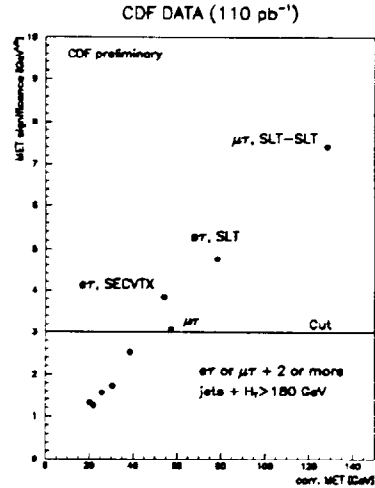

Figure 2. $\sigma_{\not{E}_T}$ versus $\not{E}_T$ distribution for τ dilepton events. The line represents the $\sigma_{\not{E}_T}$ cut.

3. LEPTON + JETS CHANNEL

In the single lepton channel the event topology consists of a high P_T, isolated lepton (e or μ), $\not{E}_T$ from the neutrino and four or more jets from the hadronization of the quarks. Events are selected requiring a lepton with $E_T \geq 20 \ GeV$ and $|\eta| \leq 1.0$, $\not{E}_T \geq 20 \ GeV$ and at least three jets with $E_T \geq 15 \ GeV$ and $|\eta| \leq 2.0$. The dominant background comes from direct production of W bosons in association with jets. It can be reduced by requiring the presence of a b quark. We use two different techniques to identify b quarks. The first one is based on the search for displaced vertices from secondary b decays (SVX tagging). Its efficiency on $t\bar{t}$ events is 0.41 ± 0.04. The second one is based on the identification, inside a jet, of low P_T leptons from semileptonic b decays (SLT). Its efficiency on $t\bar{t}$ events is 0.20 ± 0.02.
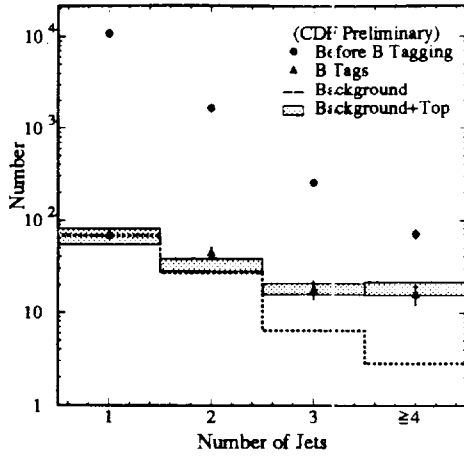
Figure 3. Jet multiplicity distribution of SVX tagged jets in the lepton plus jets channel.

With the SVX method we find 42 b tagged jets in 34 events, with an estimated background of 9.47 ± 1.4 tags. With the SLT method we find 44 b tagged jets in 40 events, with a background of 25.2 ± 3.8 tags. The main contributions to the background come in both cases from $Wb\bar{b}$, $Wc\bar{c}$ and, in the SLT case, fakes.
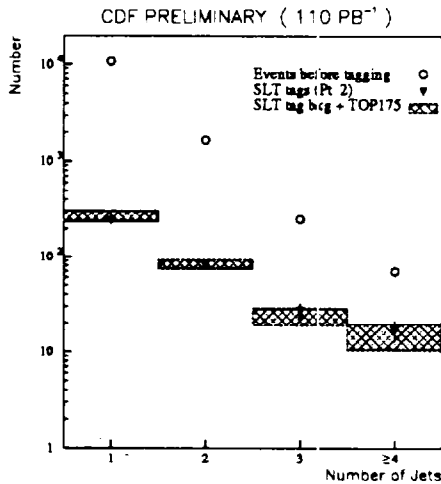

Figure 4. Jet multiplicity distribution of SLT tagged jets in the lepton plus jets channel.

In Fig. 3 we show the observed tags for the SVX tagging method as a function of the jet mul-

tiplicity of the events, compared to the expectation from the background plus $t\bar{t}$ production. In Fig. 4 the same distribution is shown for the SLT tagging method.

4. ALL HADRONIC CHANNEL

This decay channel presents a topology with 6 jets in the final state. In principle the two top quarks could be fully reconstructed because there are no neutrinos in the event. However, there is a huge QCD multijet background, orders of magnitude larger than the signal, which includes real heavy flavor production through various processes. The strategy of the analysis consists in first making a kinematic selection and then requiring the presence of b quarks in the events. The selection starts by requiring a high jet multiplicity ($N(jets) \geq 5$). We then cut on some global calorimetric variables like the total transverse energy of jets ($\sum E_T \geq 300\ GeV$), the fraction of transverse energy ($\sum E_T/\sqrt{\hat{s}} \geq 0.75$) and the aplanarity ($Apl \geq -0.0025 \times \sum_3^N E_T + 0.54$, where the sum does not include the contribution from the 2 leading jets). After this kinematic selection, we expect $S/B \approx 1/30$.
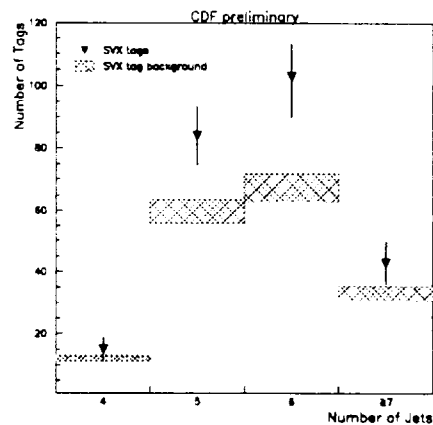

Figure 5. Jet multiplicity distribution of the tagged jets in the all hadronic channel.

The requirement of at least one SVX b tag helps to extract a signal. The final sample consists of 192 events, containing 230 b-tagged jets.

The number of tagged jets expected from background is 160.5 ± 10.4 tags. Fig. 5 shows the number of tags as a function of jet multiplicity, compared to the expected background. There is an excess of tagged jets in the jet multiplicity bins $N = 5, 6$ and ≥ 7. The significance of the excess is estimated from the probability that the background fluctuates up to the number of found tags or greater. We found a $\mathcal{P} = 1.5 \times 10^{-4}$, corresponding to a 3.6σ for a gaussian distribution.

5. PRODUCTION CROSS SECTION

The $t\bar{t}$ production cross section has been calculated in each of the samples described above. We obtain a better statistical result by combining the standard dilepton and lepton plus jets channels, after taking into account the correlations. Work is in progress to include in the measurement also the all hadronic sample, which is correlated both in acceptance and tagging efficiency with the SVX sample. Assuming $M_{top} = 175$ GeV/c^2 we obtain $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}$ pb. In Fig. 6 we show the CDF measurement compared to three different theoretical calculations for the top cross section as a function of the top mass [7-9].
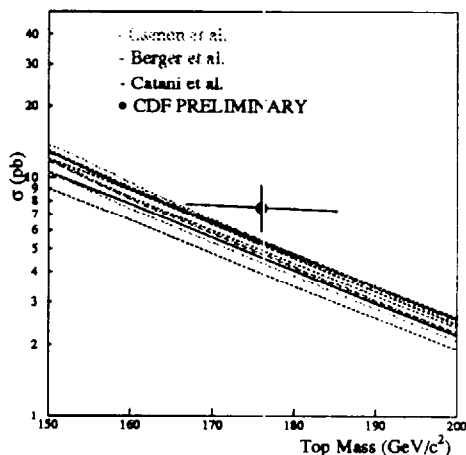

Figure 6. Combined $t\bar{t}$ cross section versus M_{top} (point) compared to theory (bands).

6. MASS MEASUREMENT

We obtain the best measurement of the top mass from the lepton plus jets channel. We start selecting the sample by requiring the presence of a fourth jet in the events. A total of 153 events is found (*pretag* sample). If we require one of the four highest E_T jets to be tagged as a b, we are left with 34 events and a background expectation of $6.4^{+2.0}_{-1.5}$ events. We fit the lepton plus jets events to the $t\bar{t}$ hypothesis, using a constrained kinematic fitting method [1]. The tagged jet is required to be one of the b-jets. Both possible solutions for the longitudinal component of the neutrino momentum are tried. Out of 12 possible combinations we choose the solution which has the lowest fit χ^2 ($\chi^2 \leq 10$). The reconstructed mass distribution is shown in Fig. 7, together with the expected background and the combination of top Monte Carlo and background returned by the fit. The fit likelihood is shown in the inset. The curve has a minimum at 175.6 GeV/c^2 and the statistical uncertainty is 5.7 GeV/c^2. The main systematical uncertainties come from the jet energy measurement and propagate to the top mass through the fit. The final top mass measurement using this method is:

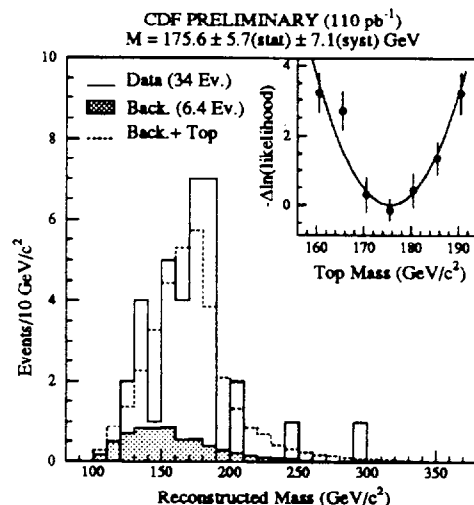$$M_{top} = 175.6 \pm 5.7(stat.) \pm 7.1(syst.)GeV/c^2.$$

Figure 7. Top mass distribution in the lepton plus jets sample for events with at least one b tag.

As an internal check, we tried to reconstruct in these events the W which decays hadronically. We select only double tagged events, so that we can assume that the other two jets in the event are from W decay. The final sample consists of 10 events. The mass spectrum is shown in Fig. 8. When we fit the peak we obtain a mass $M_W = 80.0 {}^{+5.2}_{-5.0}\ GeV/c^2$.
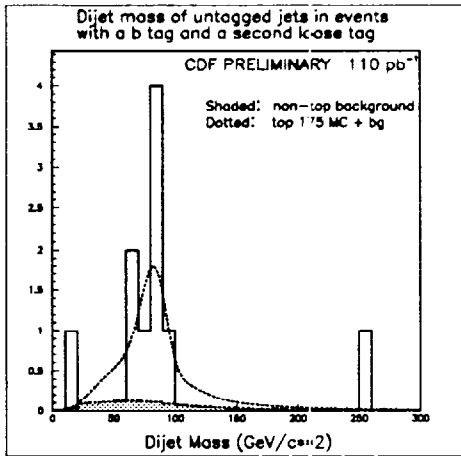

Figure 8. Dijet invariant mass for untagged jets in double tagged jet events. The peak represents the reconstructed hadronic W.

CDF has also measured the top mass in the all hadronic and in the standard dilepton channels.

In the all hadronic channel the mass distribution is obtained with a constrained fit similar to that used for the lepton plus jets sample. The final result is $M_{top} = 187 \pm 8(stat.) \pm 12(syst.)GeV/c^2$.

In the dilepton channel we use a different technique because the presence of a second neutrino makes the kinematic constrained fit impossible. We use instead the energy distribution of the two highest E_T jets in the events, which is sensitive to the top mass. The result is: $M_{top} = 159^{+24}_{-22}(stat.) \pm 17(syst.)GeV/c^2$. These results are consistent, within their errors, to the value obtained from the lepton plus jets channel. Work is in progress to combine all our top mass measurements in a single optimized result.

7. CONCLUSIONS

Using the complete data set of 110 pb^{-1} CDF isolated a $t\bar{t}$ signal in many of the decay channels, including the study of the all hadronic and τ dilepton modes.

The best measurement of the top mass comes from the lepton plus jets channel: $M_{top} = 175.6 \pm 5.7(stat.) \pm 7.1(syst.)GeV/c^2$. The corresponding measured top pairs production cross section is $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}\ pb$ (for $M_{top} = 175\ GeV/c^2$).

Fig. 9 shows the CDF and D0 top mass results combined with the W mass measurements. This information, at present statistically too limited, will eventually be used to set some constraints on the mass of the neutral Standard Model Higgs boson.
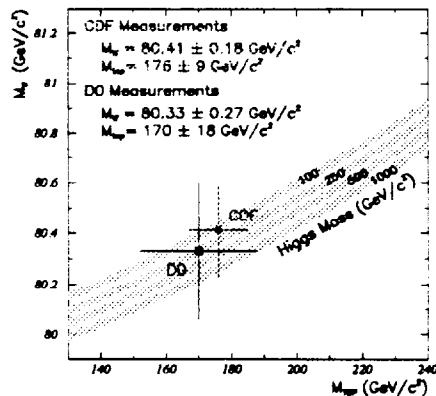

Figure 9. M_W versus M_{top} measured by CDF and D0. compared to Standard Model predictions for various H^0 masses.

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